

Overview of Induced Seismicity in Geothermal Systems

Presented to DOE

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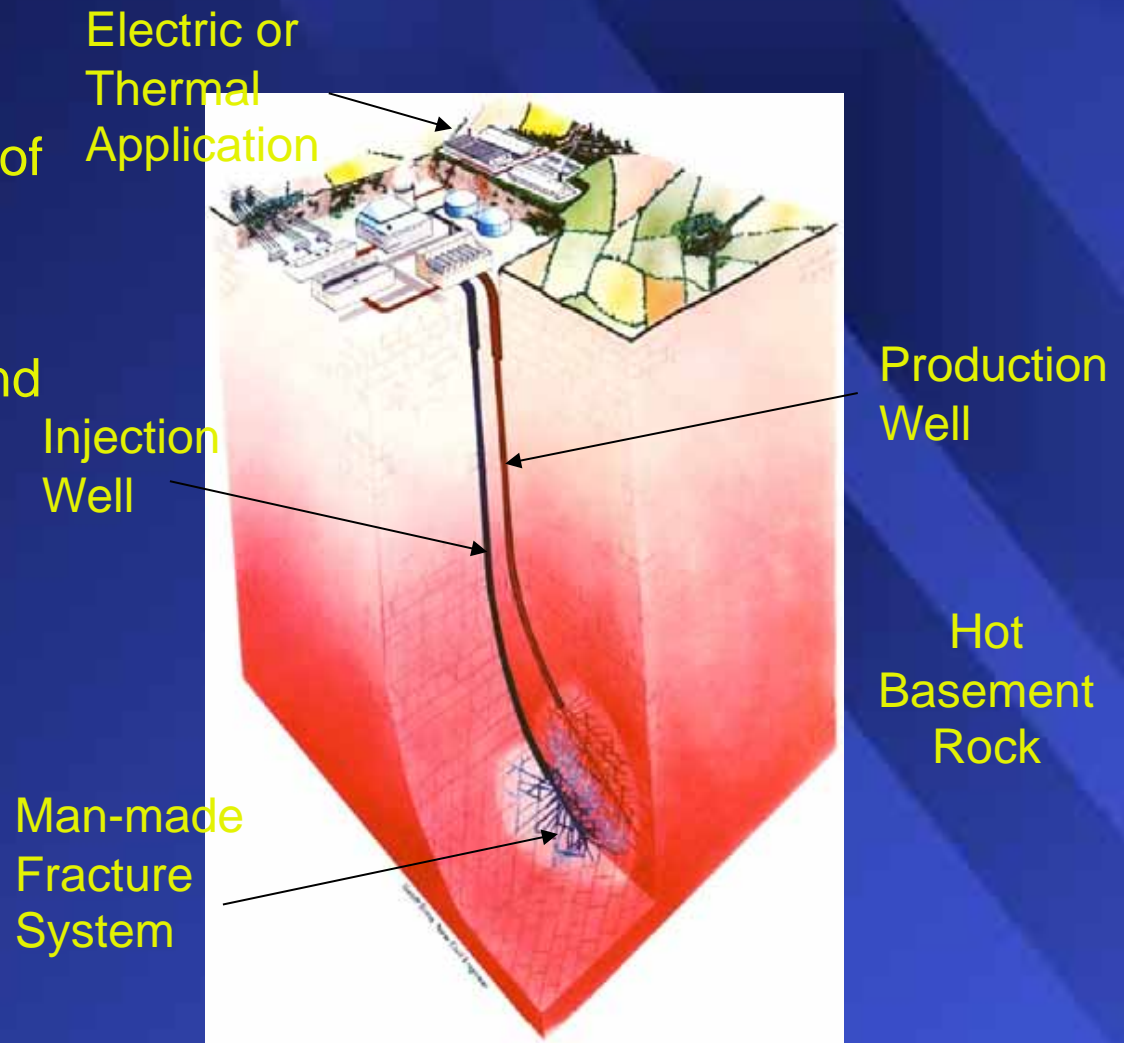
LBNL

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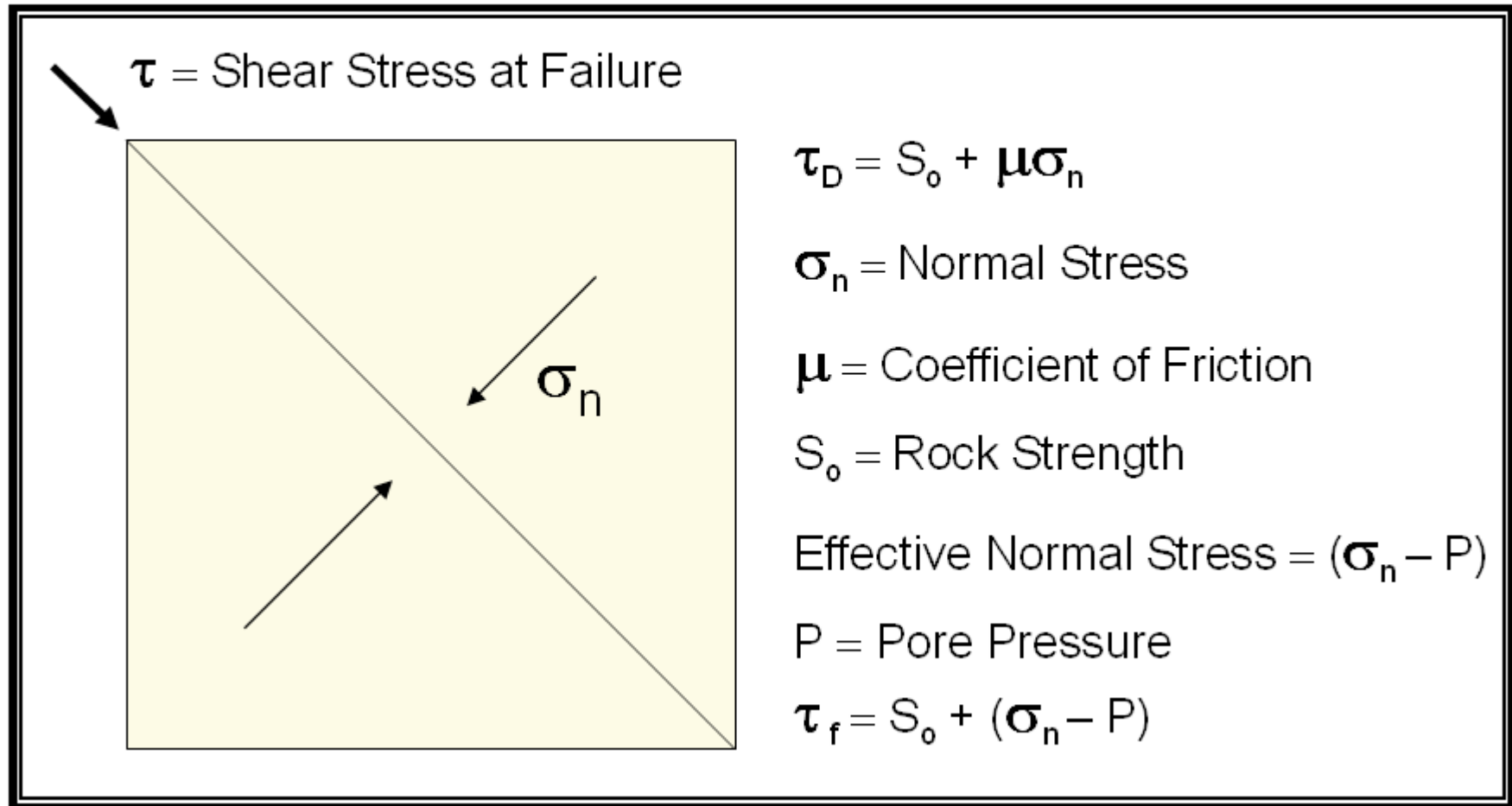


Enhanced Geothermal Systems

- Located at depths of 3-10 km
- Requires increasing permeability by stimulating, fracturing and shearing of fractures through fluid/propant injection
- Fluid circulated between injection and production wells to capture and extract heat from system
- i.e. Requires creating controlled seismicity in two different stages
 - 1 initial reservoir creation
 - (short term seismicity)
 - 2. Maintain reservoir perm.
 - Long term seismicity



Concept of Effective Stress



As P increases ($P = \text{pressure}$ “pushing against the force holding the rock together”) the fault is more likely to slip



Induced Seismicity in General

- Induced Seismicity in Non-Geothermal Areas
 - Dams/water impoundment 6.4 India
 - Oil and Gas generally < 3.0 , isolated Mag 7
 - Subsidence
 - Fluid injection
 - Mining-
 - Rock Bursts - local hazard
 - Subsidence – surface facilities if large volume removal
 - Waste disposal – Mag 5.3 (Rocky Mt. Arsenal)
 - **Almost all cases mitigated and dealt with effectively**
 - Legal Basis for dealing with impact of Induced Seismicity established in 1996
- CO₂ Sequestration could have similar acceptance Issues (however, fractures not intentionally created)

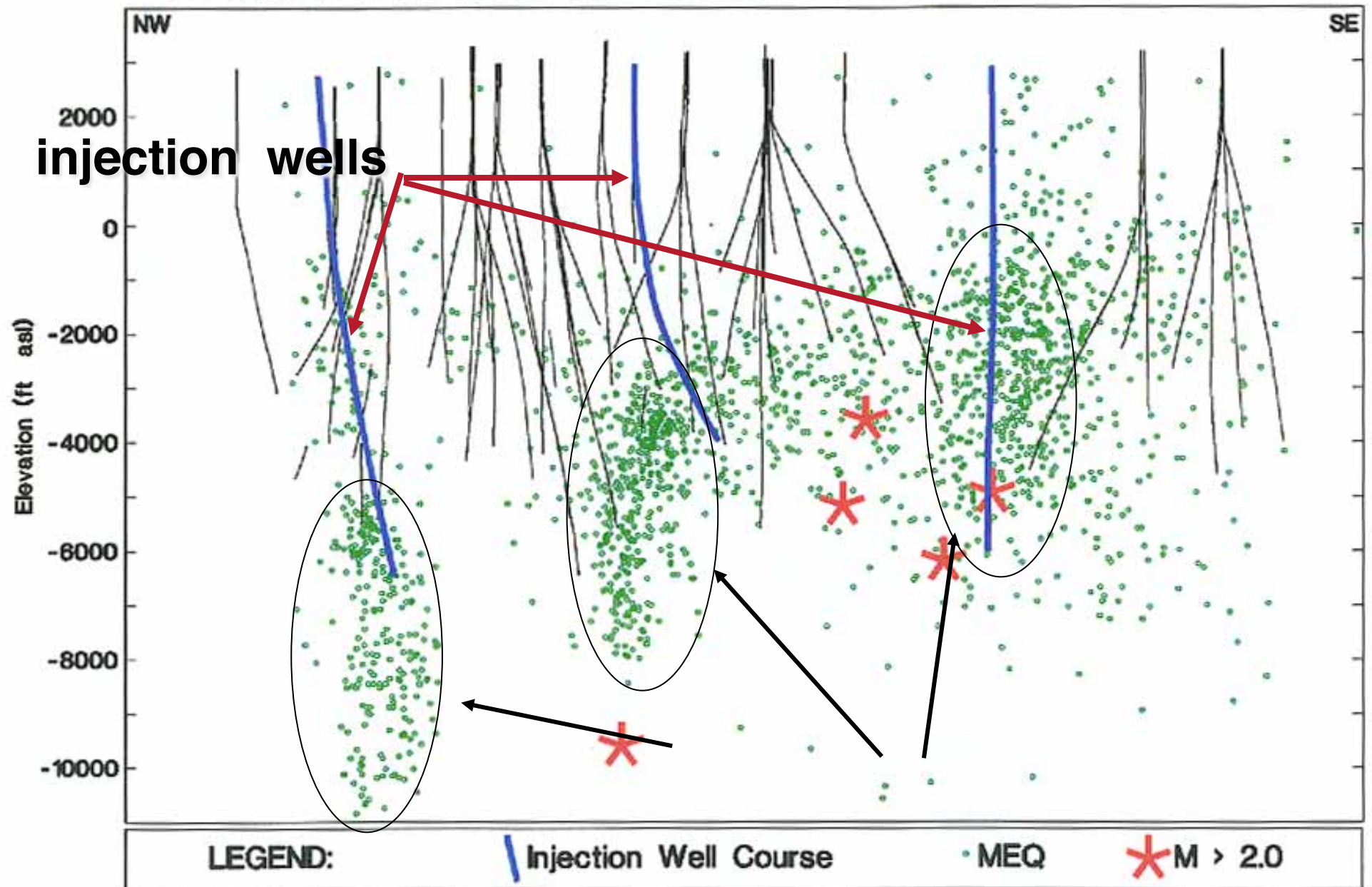


Geothermal History with Induced Seismicity

- DOE Geothermal has been studying geothermal Induced Seismicity since the 70's
- Both natural and artificial (induced permeability) geothermal systems experience induced seismicity
- Seismicity concerns have recently stopped or delayed projects
- As EGS activity increases, seismicity may become an issue with the community (sophisticated) as well as for the field operator.
- US DOE/GT recognized this in 2004 and participated in an international agreement with the IEA to address environmental issues associated with EGS.

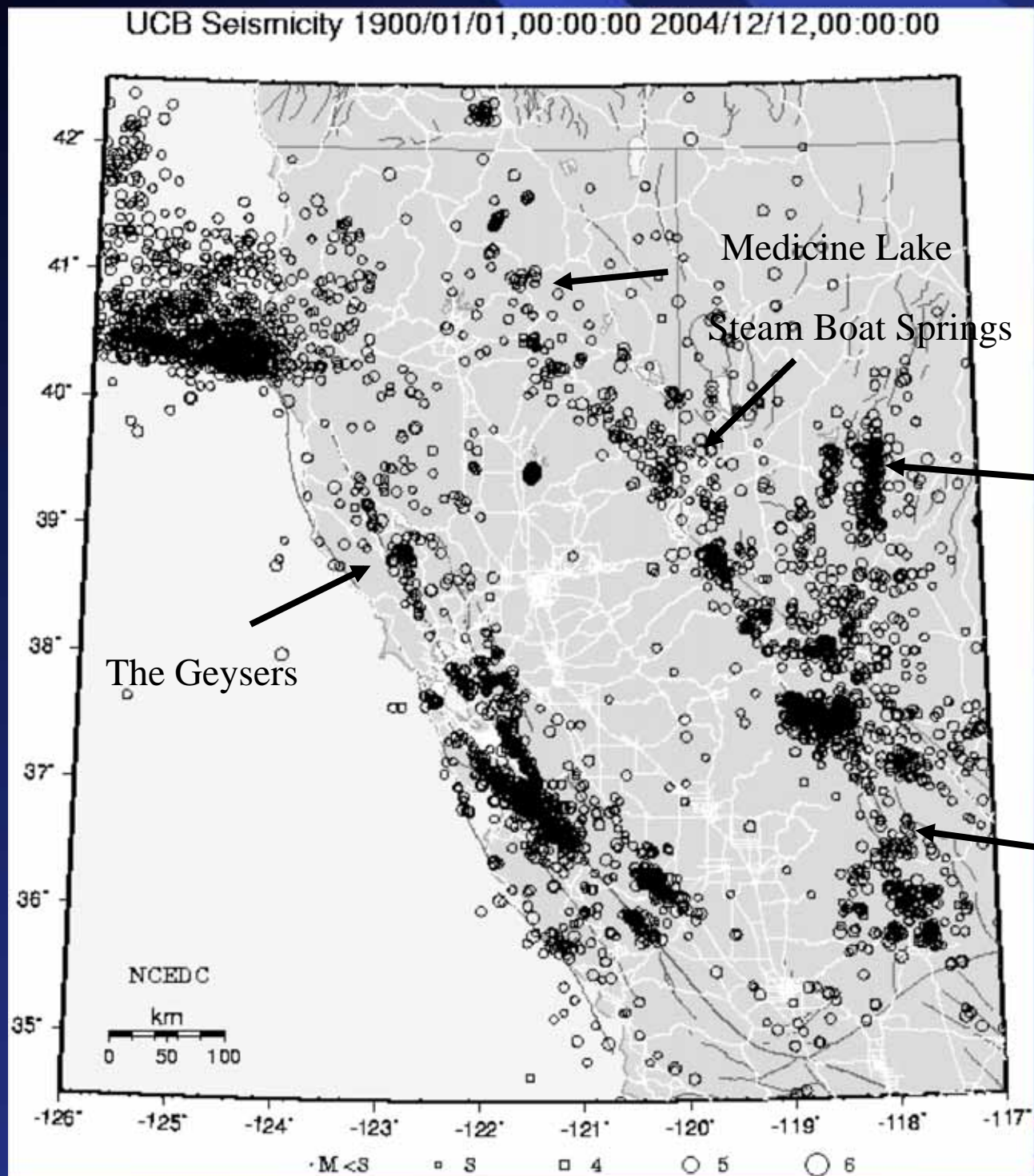


SE Geysers cross-section showing MEQ's and active injectors, 11/95 - 10/97

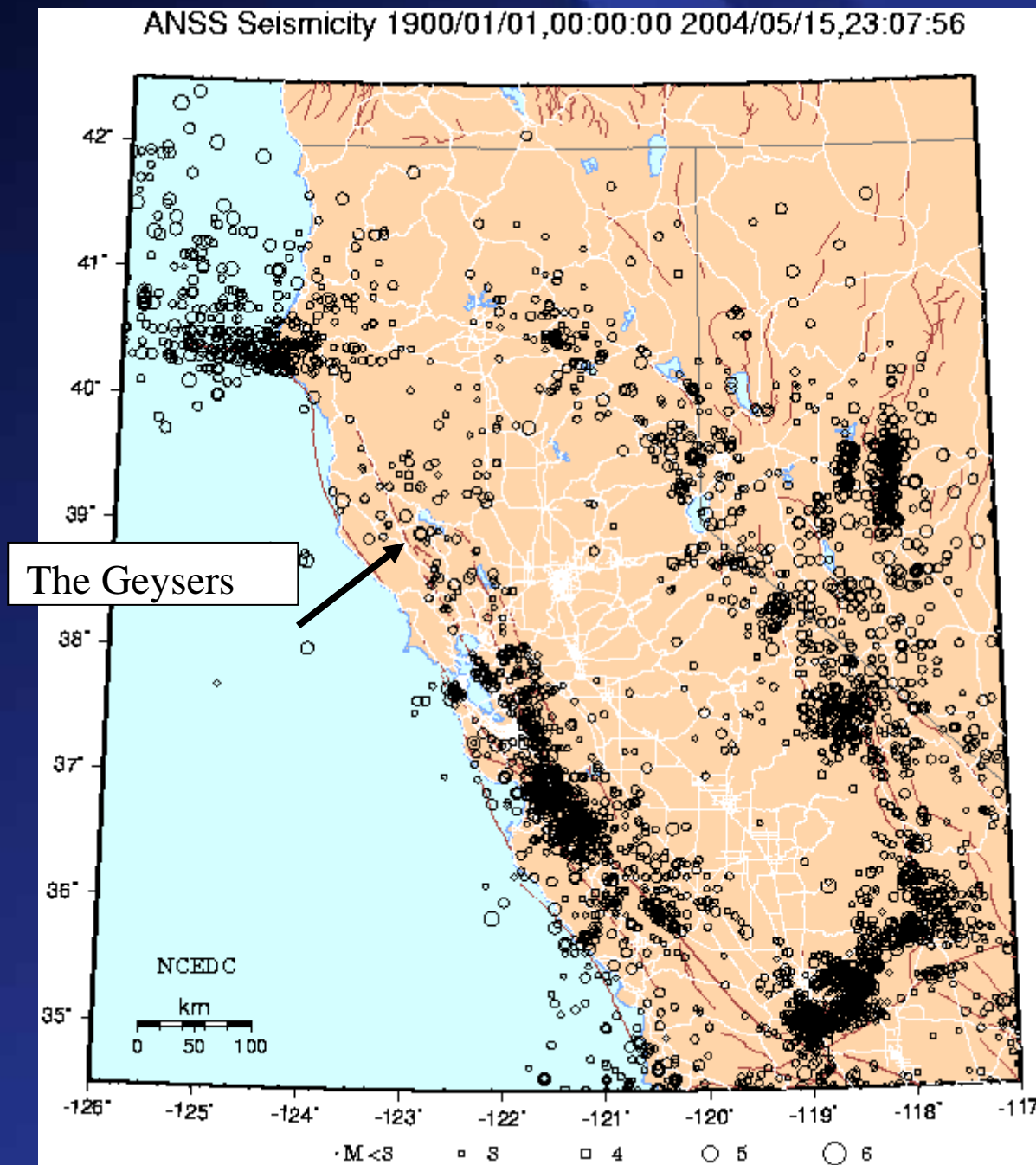


(Stark, 1999)

Mag 3
1900- 2004

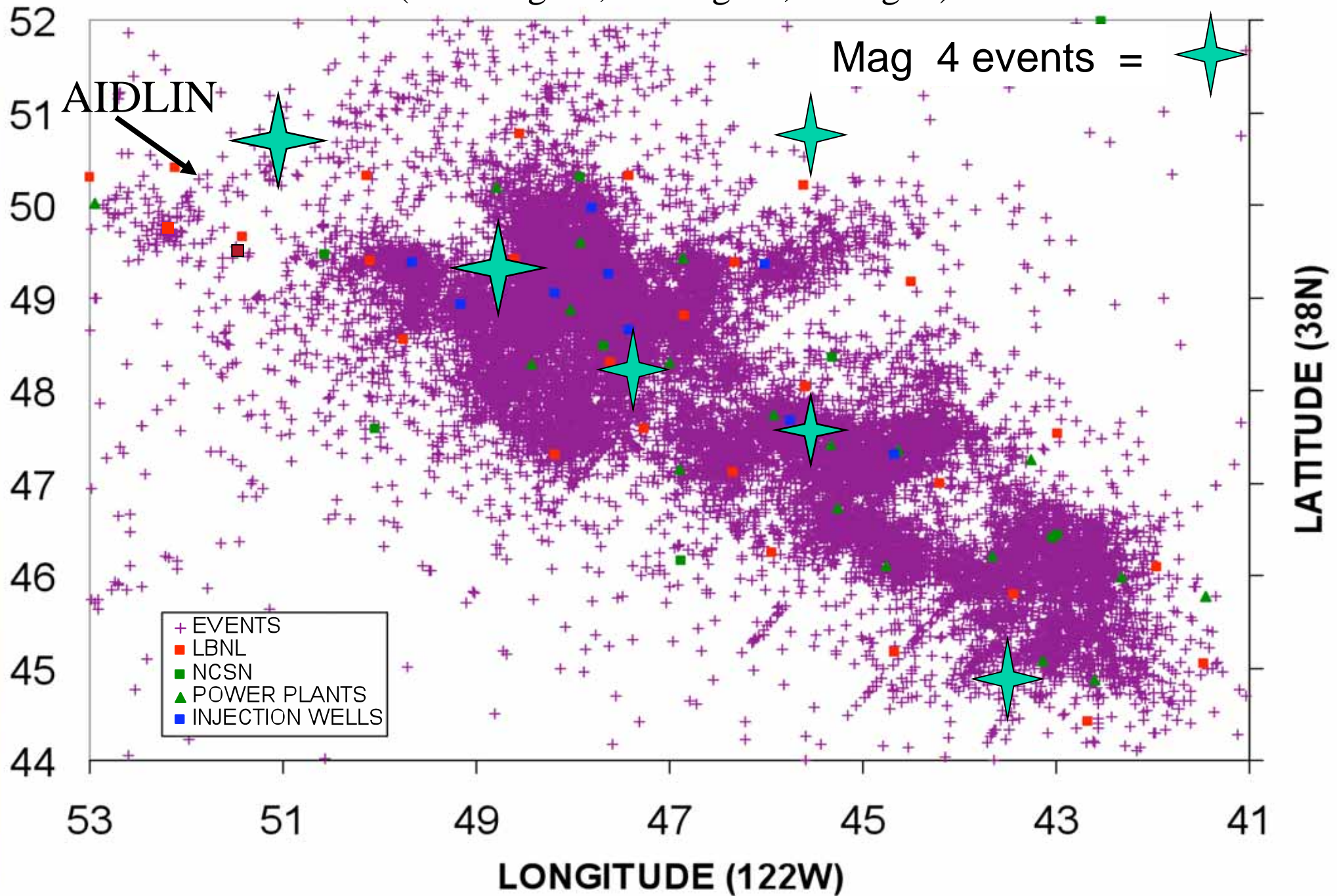


Northern California Historical Seismicity (M 3.5 to 5.0) 1900- 2005



30,000 Geysers Events > mag 0, (2.5 yrs) 2006 - 08

(310 Mag >2, 23 mag >3, 6 Mag 4)



Hypothesis for EGS Induced Seismicity

- Increased pore pressure (effective stress changes)
- Thermal stress
- Volume change (subsidence, inflation)
- Chemical alteration of slip surfaces
- Stress diffusion
- Production induced
- Injection produced
- Etc.



DOE Geothermal Process and Approach

- Draft LBNL internal whitepaper (2004)
- Three international workshops (2005-2006)
 - Form technical basis for understanding induced seismicity and a strategy for developing a protocol for designing “induced seismicity friendly” EGS projects
 - Gather international group of experts to identify critical issues (technical and non technical) associated with EGS induced seismicity
- Current products and activities
 - Peer reviewed white paper (IEA Report, Majer et al., 2007)
 - Protocol for the development of geothermal sites and a good practice guide (IEA Report)
 - Establish Website for community and scientific collaboration
 - Instrument all DOE EGS projects for monitoring induced seismicity
 - Require all DOE EGS projects to follow protocol
 - Establish international collaborations (Iceland, Australia, GEISER)



A Basis for a Protocol

- **Technical**

- Identify and understand factors controlling microseismicity
- Effect of microseismicity on man made structures

- **Legal – Community interaction**

- Propose guidelines for a geothermal developer to deal with the issue of induced seismicity.
- Inform and interact with the community to understand their concerns and partner with them to achieve a win-win situation

Both are linked and overlapping



Technical Issues

- Assess Natural Seismic Hazard potential
 - Historical seismicity, tectonic setting
 - Rate of seismicity
- Assess Induced seismic Potential
 - Examine other injections in area (if any)
 - Geologic surface conditions
 - Proximity to communities
 - Maximum probable event (rate and volume, pressures, stress state, etc)
 - Does the seismic hazard change due to induced seismic potential?
- Establish Microseismic Monitoring network
 - Necessary resolution and accuracy
- Implement procedure for evaluating damage
 - Strong motion recorders
 - Compare to other activities
- Establish mitigation procedures

Non Technical

- Review laws and regulations
 - Local laws will differ
- Establish dialogue with regional authority
 - Necessary permits, public announcements, meetings, regulatory permits
- Educate and interact with stakeholders
 - Public outreach
 - Explain benefits



Gaps in Knowledge

- Relationship between the small and large events
 - Similar mechanisms and patterns
 - Threshold of events/ triggered?
 - Why do large events occur after shut in.
- Source parameters of events
 - Stress drop versus fault size
 - Indication of stress heterogeneity?
 - Seismicity on existing versus new faults - fractures
- Experiments to shed light on mechanisms
 - Variation of key parameters (injection rate, vol., temp, pressure, etc.)
- Differences between Natural and Induced fracture systems
 - Maximum size, time of events
- Can one manipulate seismicity without compromising production?
 - Does the reservoir reach equilibrium?

Path Forward/Needs



• Technical Issues

- Further understanding of complex interaction between stress, temperature, rock and fluid properties
- Alternative methods for creating reservoir
 - “nudge and let it grow” versus massive injections

• Community Interaction

- Supply timely, open, and complete information
- Technical based risk analysis



• Modeling/Theory Needs

- Fully coupled thermo-mechanical codes
 - Stress, temp, and chemical effects
 - Examination of fracture creation
- Joint inversion of EM/seismic data
 - Links fluid and matrix properties
- Full anisotropic 3-d models for reservoir imaging
 - Fracture imaging at different scales



- Data Needs

- Improved high pressure-high temperature rock physics data
 - Rock physics measurements
 - Coupled chem/mechanical
- High resolution field measurements
 - Dynamic fracture imaging
 - High res MEQ



• Infrastructure

– Field

- High temp (>250 C), high pressure instrumentation (logging)
- High resolution MEQ arrays
- Low cost drilling for high density, high resolution monitoring
 - Microdrilling

– Lab

- High Temp/pressure Rock Physics Laboratory
- High Temp/Pressure tool testing capability
- Geothermal geochemical analysis capability

– Computational

- Dedicated parallel processing cluster



Policy Needs

- Require EGS operators to follow protocol
 - Update as EGS technology progresses
 - Follow technical and community/regulator interaction
- Develop risk based procedure for estimating potential mitigation requirements
 - Probabilistic
 - Physics based



Status of EGS Induced Seismicity

- Technical basis for understanding and controlling EGS induced seismicity has been established.
 - White paper and protocol finished and adopted by IEA
- Issues are similar to other induced seismicity cases which have been successfully addressed
- Issues are both technical and non-technical
 - Must pay attention to both
 - Seismicity can be a benefit in understanding the resource
 - Technical issues remain on fully utilizing seismicity as a reservoir management tool
- Induced seismicity is not (or need be) an impediment to EGS development

